High Frequency Bottom Interaction in Range Dependent Biot Media

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LONG TERM GOALS

The long term objective of this project is to understand the dominant physical mechanisms responsible for propagation, attenuation and scattering in low shear velocity, porous sediments such as found on continental margins. Many Navy acoustic systems operate at high frequencies in shallow water over soft, fluid-saturated sedimentary bottoms. In many environments the bottom has range dependent properties such as seafloor roughness or volume heterogeneities within the seafloor. To optimize the performance of these Navy systems it is necessary to fully understand the behavior of acoustic wave propagation and scattering in these complex environments.

OBJECTIVES

The finite difference method has proven to be useful in studying acoustic wave propagation in complex media where other methods become invalid. We propose here to extend our Numerical Scattering Chamber, which is based on the finite difference method, to include poro-elastic effects based on Biot theory. With the extended code we will study propagation and scattering effects in real high frequency data from sedimentary environments.

Prior work in non-porous media shows that scattering from wavelength size heterogeneities can be responsible for body waves in the sub-bottom that would not be predicted based on Snell's Law Ray Theory using mean medium properties. This phenomenon will cause anomalous sub-bottom penetration and will be relevant for accurately predicting forward and back scatter from realistic environments. We anticipate that similar mechanisms will take place in Biot media and we need to quantify the effect of porosity on the bottom penetration issue. How far below the seafloor do we need to know geophysical parameters in order to accurately predict backscatter in porous environments?

APPROACH

We have perceived a need for reference solutions for Biot media representative of shallow seafloor environments. We will host a workshop on "Propagation and scattering in range dependent porous media" at Woods Hole, on May 22-23, 2000. The goal of the workshop is to compare various analytical and numerical solutions to a set of benchmark models. Benchmarks will be constrained by geological and geophysical data that has been acquired by ONR (Stratiform, CBBLE, etc) in shallow water environments of relevance to the Navy. There is a role for simple canonical models but in at least one case we would want to replicate an existing acoustic data set.

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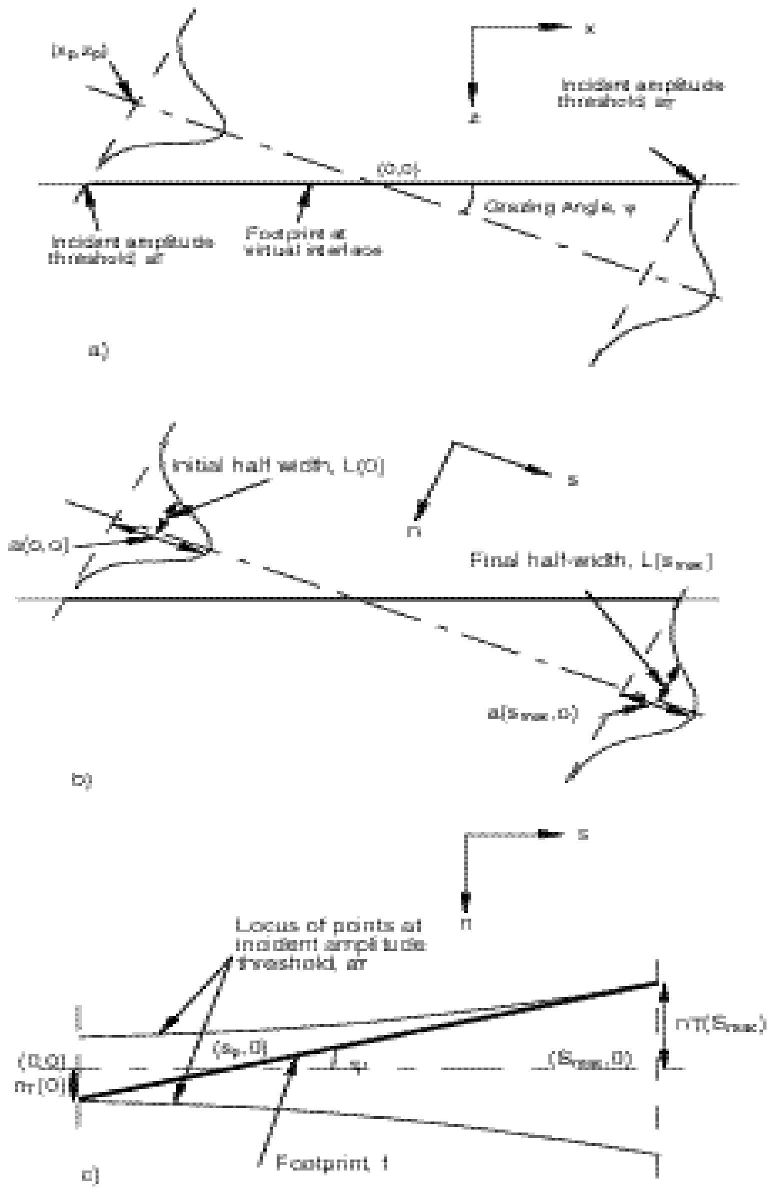

Figure 1: The optimum Gaussian beam for surface scattering problems is defined on the notion that the beam will spread as it propagates across a flat virtual interface at the mean level of the surface. Optimum beam parameters are constrained by the grazing angle and the incident amplitude threshold. The incident amplitude threshold is the maximum acceptable incident amplitude at the edges of the scattering region and is chosen based on an acceptable level of artifacts from edge effects. The minimum half-width occurs at the beam waist. The origin is defined at the intersection of the beam waist and the virtual interface. The center of the beam waist is located at (x_p, z_p). The footprint size is the distance along the virtual interface between the lower and upper incident amplitude threshold points. To compute parameters for the optimum beam it is convenient to work in beam coordinates (s, n). (Figure from Stephen, in press.)

WORK COMPLETED

A preliminary review of published formulations of the wave equations for heterogeneous, porous media was presented in Stephen (1997). Plans for a workshop on benchmark models for fluid saturated porous media have been initiated (Stephen, 1998). We have a finite difference code for obtaining solutions to range dependent problems including porous, elastic media in 2-D.

Many formulations for seafloor scattering problems could benefit from a rigorous definition of the insonifying field that is physically realistic (ie a solution to the wave equation) within a truncated spatial domain (ie the scattering region on the seafloor has a finite size) but is still restricted to a small range of grazing angles. Gaussian beams meet these requirements and a paper is in press outlining the merits of Gaussian beams in time-domain finite-difference methods (Stephen, in press). For a CW beam at a given angle of incidence and a given incident amplitude threshold, there is an 'optimum' beam which minimizes the scattering area on the interface (See Figure 1). The concept of the optimum beam for CW sources can be extended to 'standard' beams for band-limited, pulse sources.

RESULTS

All of the familiar equations from Biot's porous media papers, assume uniform porosity and homogeneous material. In our finite difference approach we rely on gradients of elastic parameters (and porosity) to compute the effects of interfaces. It is important to have the correct equations for heterogeneous, "non-uniform" porosity material. A finite difference solution for a homogeneous, "uniform porosity", medium was treated by Zhu and McMechan (1991). Dai et al (1995) solved Biot's equations for a heterogeneous, "uniform porosity" medium. None of these approaches is satisfactory for our applications.

The equations used in our time-dependent finite-difference (TDFD) code and the assumptions made are outlined in Stephen (1997). An example of a solution for a point source in a homogeneous, porous medium is also presented. A thorough presentation of Gaussian beam incident fields, which are useful in TDFD methods to minimize the spatial domain, is given in Stephen (in press). This material will form the basis of our solutions for the porous media workshop.

IMPACT ON SCIENCE AND TECHNOLOGY

We expect that our TDFD code and other approaches presented at the porous media workshop will permit a quantitative study of the importance of porous media theory to propagation and scattering models in shallow water environments at high frequencies. Is porous media theory applicable to real problems? What are the best ways to define the necessary parameters for a porous media? Are there alternative explanations for anomalous features in field data? What are the dominant physical mechanisms for scattering, propagation and attenuation in porous media? These issues go well beyond seafloor acoustics and will have significant impact on the fields of physical acoustics, aero-acoustics and medical acoustics.

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